REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(LEAVE BLANK)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	8 July 1999	Professional Paper

4. TITLE AND SUBTITLE

Dynamic Strength Capabilities of Small Stature Females to Perform High Performance Flight Tasks

5. FUNDING NUMBERS

6. AUTHOR(S)

Barry Shender, Ph.D. Peggy Heffner, M.S.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Air Warfare Center Aircraft Division
22347 Cedar Point Road, Unit #6
Patuxent River, Maryland 20670-1161

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Naval Air Systems Command
47123 Buse Road, Unit IPT
Patuxent River, Maryland 20670-1547

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

NAWCAD investigated the abilities of small stature females (≤ 120 lb) to fly under G-stress using the Dynamic Flight Simulator (DFS) and its tactical fight/attack cockpit, displays and controls. The objective was to determine if these individuals possess sufficient muscular endurance to perform tasks required during fighter pilot training, aerial combat maneuvers, and failure modes. Methods: Five subjects (four small stature females and one medium female) participated. DFS tasks featured bombing runs, SAM avoidance, and single engine failure. Muscular exertion and fatigue (arm, shoulder, neck) were assessed using EMG. Results: Flight performance did not significantly degrade over time. Human factors deficiencies were noted in the areas of torso harness fit, inertia reel placement relative to shoulder width, and the ability to maintain a full range of stick motion. Conclusions: Within the scope of these tests, small stature females demonstrated the strength and endurance to safely fly physically strenuous missions. However, cockpit accommodation and pilot reach limits may hinder the small stature pilot during flight emergencies.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Women Dynamic strength High Performance Flight G-stress EMG	40
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

Number of words: 4848

Number of references: 9

Number of pages: 40

Number of tables: 12

Number of figures: 2

Dynamic Strength Capabilities of Small Stature Females To Perform High Performance Flight Tasks

Barry S. Shender, Ph.D., Peggy L. Heffner, M.S.

Naval Air Warfare Center Aircraft Division

Patuxent River, Maryland

USA

20670-1906

Correspondence and address reprint requests to: Barry S. Shender, Ph.D., NAWCAD, BLDG 2187 SUITE 2280, 48110 Shaw Road UNIT 5, Patuxent River, MD, USA, 20670-1906. Tel: 301-342-8881, Fax: 301-342-8876, e-mail: ShenderBS@navair.navy.mil

Running Head: Dynamic Flight Tasks

ABSTRACT

Background: Naval Air Warfare Center Aircraft Division investigated the abilities of small stature females (≤ 120 lb.) to fly under G-stress using the Dynamic Flight Simulator (DFS) and its tactical fight/attack cockpit, displays and controls. The objective was to determine if these individuals possess sufficient muscular endurance to perform tasks required during fighter pilot training, aerial combat maneuvers, and failure modes. ***Methods***: Five subjects (four small stature females and one medium female) participated. DFS tasks featured bombing runs, SAM avoidance, and single engine failure. Muscular exertion and fatigue (arm, shoulder, neck) were assessed using EMG. ***Results***: Flight performance did not significantly degrade over time. Human factors deficiencies were noted in the areas of torso harness fit, inertia reel placement relative to shoulder width, and the ability maintain a full range of stick motion. ***Conclusions:*** Within the scope of these tests, small stature females demonstrated the strength and endurance to safely fly physically strenuous missions. However, cockpit accommodation and pilot reach limits may hinder the small stature pilot during flight emergencies.

Keywords: women, dynamic strength, high performance flight, G-stress, EMG

Since 1993, women have had an increased role in military combat operations, including piloting high performance aircraft. Stature requirements for women has also expanded to include 82% of the US female population, including those in the fifth percentile for weight, i.e., 120 pounds or less. It is essential to determine if such individuals can perform certain tasks under dynamic conditions given their small stature. In particular, this study addresses whether these females possess the upper body muscular endurance to perform high performance flight maneuvers such as those experienced in training, air combat and during emergency flight conditions.

In general, measures of female <u>mean</u> strength are comparable to males for various dynamic lifting, pushing and pulling activities (5). Women appear to be at a disadvantage relative to men for muscular exertions involving flexion, abduction and rotation of the arm about the shoulder, possibly due to smaller muscle moment arms. Gender differences reported in population strength data are almost entirely explained by differences in muscle size as estimated by lean (fat-free) body weight or limb cross-sectional area (circumference measurements) dimensions (5). However, gross anthropometric descriptors alone are not sufficiently correlated with strength to be of practical value. If a man and woman with similar fat-free body weight are trained to the same degree, their isometric muscle strength performances will be comparable (5). Caldwell (4) stated that, "While arm strength may be related to arm dimensions, stature and weight, endurance is not."

A review of nine separate studies conducted by Laubach (7,8), found that even though flight related upper body exertions should be within average female muscular abilities, small stature and weight females may not be able to generate sufficient muscular force in all planes of motion.

Overall, female upper extremity strength was found to be 35 to 79% of men's (mean 55.8%); female lower extremity strength was 57 to 86% of men's (mean 71.9%); female trunk strength was 37 to 70% of men's (mean 63.8%); and with reference to dynamic strength indicators, females were 59 to 84% as strong as males (mean 68.6%).

LCDR T. L. Pokorski of the Naval Aerospace Medical Research Laboratory conducted a survey of aircraft model managers in 1994 in which muscular strength and endurance requirements for various critical tasks performed in USN fixed wing aircraft were assessed (see summary in reference 9). The managers indicated which tasks required muscular strength (isometric) and/or endurance, if they involved arm, leg, abdominal, neck muscle group, or whole body exertions, what the frequency of these critical tasks (once, few or many) was and whether such tasks were considered emergency or survival tasks. For high performance aircraft, brute strength was clearly not of concern. The most critical muscular strength requirement was the need for sufficient muscular endurance, particularly during high-G maneuvers.

Purpose

The purpose of this study was to determine the ability of small stature females to perform upper body muscular endurance tasks associated with standard fighter pilot training, aerial combat maneuvers, and in-flight failure modes. A separate report concerns the ability of these subjects to eject and support up to 5 lb. of head borne weight.

Scope

The intent of this study was to determine the range of dynamic strength capabilities of small stature females and any limitations they might have that would impair their ability to accomplish high performance aircraft tasks. In particular, the focus was on those tasks encountered in a "fly-by-wire" aircraft, such as an F/A-18. As such, generalization of these results to flight performance in aircraft employing mechanical controls which require greater muscular strength should be done with great caution. Subjects were deliberately selected to represent the worst case in terms of size and experience to determine what modifications, if any, in terms of training and/or equipment would be required to accommodate this expanded population.

Nothing is mentioned during discussion of mil or civ. Ps. Is this just for comparison purposes?

METHODS

To achieve these objectives, four small stature (defined as ≤ 120 lb. (54.5 kg)) women (33.3 ± 2.6 yr.) were recruited to participate in this study. Mean anthropometric descriptions of these subjects were: weight: 51.3 ± 1.8 kg; height: 158.3 ± 4.9 cm; functional leg length: 97.7 ± 1.5 cm; sitting height: 84.2 ± 3.4 cm; sitting eye height: 73.2 ± 2.6 cm; sitting acromial height: 56.5 ± 2.5; thigh clearance: 14.7 ± 0.4 cm; buttock-knee length: 55.6 ± 0.8 cm; sitting abdominal depth: 21.0 ± 1.4 cm; sitting hip breadth: 37.4 ± 2.0; thigh circumference: 53.1 ± 1.4 cm; thumb tip reach: 71.6 ± 2.2 cm; and VO_2 max: 38.0 ± 2.4 $ml \cdot kg^{-1} \cdot min^{-1}$. In comparison to the NAMRL database of 152 women subjects (9), these subjects were 26% lighter in weight and their anthropometric measurement ranged between 2 and 11% smaller. By using a push/pull task to measure isometric flexion, extension and lateral neck strength, mean peak neck strengths were:

flexion 18.3 ± 2.9 lb; extension: 24.3 ± 7.5 lb; right: 17.5 ± 3.7 lb; 17.5 ± 5.5 lb. In addition, one medium stature woman who held a private pilot's license also participated. Due to scheduling problems not all five subjects participated in all tasks. Informed consent was obtained from all subjects prior to the conduct of this investigation in accordance with SECNAVINST 3900.39B and all pertinent DHHS regulations.

These studies were conducted at the Dynamic Flight Simulator (DFS) facility in Warminster, PA. Installed in the DFS gondola was a cockpit which had been determined to have the same dimensions and control layout as in an actual F/A-18D aircraft. The flight simulation was driven by Silicon Graphics Incorporated (SGI) equipment and CTA Simulation System's (Englewood, CO) Mission Simulation Software. Three 21" video monitors were mounted in the centrifuge to display out-the-window imagery. The virtual reality visual scene gave the subject a 35° vertical by 120° horizontal field-of-view. The scenery was produced by SGI Reality Engine graphics and was a highly textured database of the Oakland/San Francisco Bay area.

To determine localized upper body muscular fatigue and effort levels, electromyographic (EMG) electrodes were affixed on the biceps brachii (flexor, BM), brachioradialis (flexor, BRM), triceps (extensor, TM), and deltoid (shoulder abduction, extension, flexion, rotation, DM) muscles (6). Two Ag-AgCl electrodes were placed about 1 cm apart in the middle of the belly of the muscle and oriented perpendicular to the muscle fibers. The EMG reference electrode was placed on the dorsal side of the forearm over the ulna, an electrically unrelated tissue (2). ECG was also monitored. Subjects wore a flight suit, flight gloves, an SV-2 survival vest, a torso harness, and a COMBAT EDGE ensemble (pressure vest, HGU-68/P helmet and low profile mask) with a

first generation female sized EAGLE suit (Enhanced Anti-G Lower Ensemble). During G exposures, the EAGLE suit was inflated relative to G-load (pressure (psi) = 1.5 *(G-1)) and torso and mask positive breathing pressure began at +4 Gz and increased at 12 mmHg/G.

Muscular exertion strength was assessed in the time domain by calculating the EMG root-mean-square (RMS) value. Stronger exertions resulted in higher EMG amplitude. Relative estimates of muscular fatigue were made by determining the EMG frequency content by first passing the EMG through a Hamming Window then calculating the power spectral density (PSD). The frequency content of surface EMG waveforms decreases (shift to lower components) when a contraction is sustained. This frequency shift can be used to estimate muscle fatigue. Based on a recommendation by Basmajian and DeLuca (2), the characteristic frequency chosen to track was median frequency. Subjects also verbally rated their level of exertion based on the Angel, et al, scale (1) which is an improvement of the Borg (3) scale for muscular exertion tests, and a modified Borg scale was used to estimate subjective fatigue.

Performance decrements referable to a decline in muscular endurance are caused by muscular fatigue brought about by long periods of sub-maximal exertions. For example, a pilot may perform a sequence of engagements which feature short duration sustained G turns (e.g. 3 - 4 s average, typically no more than 10 s), followed by unloading the aircraft, regrouping, and pulling G's again. Another demanding task involves a training sequence of bombing runs, including high +Gz pull outs, which are repeated up to two dozen times. Muscular endurance becomes a critical factor during asymmetric flight in which one engine is inoperative and the pilot has to maintain about 10 lb. of force on the stick (as opposed to the normal 0 lb.) and a sub-maximal

load on the rudders to maintain trim for up to 60 min. and then having to land on an aircraft carrier during adverse conditions.

To simulate these muscular endurance tasks, subjects were trained in the DFS to perform simulated bombing runs, a SAM avoidance pattern, and an engine-out scenario with landing tasks. During initial training, subjects became familiar with flight instrument operations; how to develop an effective instrument scan pattern; and controlling altitude, airspeed, attitude, and G-load with the DFS in the static (1g) mode. Then the subjects practiced under dynamic conditions in which the aeromodel G-levels were scaled relative to actual +Gz-loads and progressively increased as their skills improved up to a peak acceleration of +7.5 Gz.

A high-G multiple turn task (scaled for a +9 Gz aircraft) simulated a SAM avoidance type scenario. Subjects performed a series of level turns at a different altitude for each turn. This provided the same overall G exposure as recorded from a HUD tape during Operation Desert Storm in which an F-16 pilot evaded multiple SAMs. The sequence consisted of a 4 s +7.2 Gz left turn at 10,000 ft AGL (80% of maximum load of a +9 Gz aircraft), then a 10 s descent to 9,000 ft AGL, followed by a 4 s +3.6 Gz right turn (40% of maximum load), then a 10 s ascent to 11,000 ft AGL, followed by a 4 s +5.4 Gz right turn (60% of maximum load), then a 10 s descent to 10,000 ft AGL, at which point the sequence was repeated. Fig. 1 shows an idealized +Gz profile and altitude changes for one set of turns. Overall, 24 sets of these three turns were completed in about 45 min. SAM avoidance flight performance was assessed based on the weighted grading scheme shown in Tables I and II. Points were awarded based on the subjects' ability to maintain the target G level and altitude with a minimum of oscillations. This was determined by calculating the mean

sum of squared errors (Mean SSSE) and the r^2 value with respect to the time of the turn (4 s). If the oscillations were effectively damped, then Mean SSSE should be minimal and r^2 should approach 1.0. To gauge the quality of the turn for G-load, time spent in the good range (+7.2 ± 0.3 Gz; +5.4 ± 0.2 Gz; +3.6 ± 0.1 Gz), in the fair range (+7.2 ± 0.5 Gz; +5.4 ± 0.3 Gz; +3.6 ± 0.2 Gz), sum of squared errors between target G-load and actual G-load (Target SSSE) and the r^2 value between target G-load and actual G-load were calculated. To quantify subjects' ability to hold desired altitude, time spent in the good range (target ± 50 ft), in the fair range (target ± 75 ft), sum of squared errors between target altitude and actual altitude (Target SSSE), the r^2 value between target altitude and actual altitude (r^2 target), and if they reached the target altitude to begin the turn within ±100 ft in the allotted time were calculated. To determine the weight of the SSSE values, an average over the entire series of turns for a given G-load and subject was calculated and points were awarded for how close an individual turn was to that overall mean.

Arm and shoulder muscular effort and fatigue were determined by measuring EMG RMS and f_{med} values for the first and every fourth set of turns. To determine changes in muscular effort, the change in EMG RMS for later turn sets was compared with the first set of turns for each +Gz level. Then, a repeated measures ANOVA was conducted with the subjects as a random factor and run number as a fixed factor, followed by a Fisher's Least Significant Difference post hoc test.

TABLES I AND II AND FIG. 1 HERE

The simulated bombing run consisted of a subject flying the aircraft to a predetermined waypoint, then performing a modified high pop maneuver (initial pass only), inverting at 10,000

ft, diving at +4 to +5 Gz, rolling upright and releasing a bomb at 8,000 ft AGL to SAM sites located at an airport. Then the subject executed a high +Gz pull up such that the aircraft descended no lower than 5,000 ft AGL and flew outbound to the next waypoint marker. Subjects then performed a +4 Gz turn and returned to the airport to deliver more ordnance on the SAM sites, diving from 10,000 ft. This pattern was flown continuously for one hour, completing up to nineteen passes to hit nine targets. Fig. 2 shows an idealized +Gz profile with altitude changes during one bombing run. Subjects' subjective fatigue levels were recorded after each bombing run and analyses of the changes in EMG and flight performance were concentrated on the bombing run, since this phase of the scenario was considered the most physically taxing. Flight performance was based on the ability to (1) hit all nine ground targets during each one hour insertion in the centrifuge gondola, (2) release ordnance at 8,000 feet, (3) pull out without descending below 5,000 feet and the ability to pull a constant G-load after weapons release during pull out.

FIG.2 HERE

Data were analyzed during the first and every fourth set of bombing runs. There was relatively little effort required during the early phases on the bombing run, i.e. the initial roll inverted, sighting the target, and rolling upright and pressing the bomb release switch. Therefore, EMG analysis centered around the period of maximum effort - a 6 s sample during pull out after weapons release, as well as examining the change in TM and DM activity as subjects transitioned from flexing the arm during pull out to extending the arm as they leveled the aircraft while flying away from the target area. Statistical treatment of EMG data was similar to the SAM Avoidance Simulation.

To simulate the muscular effort required to control an aircraft during the emergency engine-out scenario, subjects first performed an ILS (Instrument Landing System) task with the control stick in the normal mode and the right rudder pedal partially depressed (between 1/3 to 2/3 fully depressed) as an experimental control. Then the control stick was modified so that the subject had to apply constant back pressure on the stick (equivalent to a +3 Gz pull) to maintain trim. Then subjects performed an ILS task, waved-off and flew an oval pattern for approximately twenty minutes, and finished by repeating the ILS task. Performance and muscular fatigue assessment was based on the difference between the first ILS compared with the second. The relative magnitude of the level of muscular effort required by the task was determined by comparing subject performance between landing with the stick in the control mode versus the loaded stick using a repeated measures ANOVA. Engine out scenario flight performance was assessed similarly to the SAM Avoidance task. The weighted grading scheme is shown in Table III. The task gauged subjects' ability to (1) maintain target altitude, airspeed and heading during the approach to the ILS glide slope intercept (APP – 48 total points); (2) maintain required airspeed, heading, and glide slope angle while following the glide slope to the airport (GS – 48 total points); and (3) wave off above the 150 ft minimum altitude (4 points). To determine the subjects' ability to maintain controlled flight during APP, the mean SSSE and r^2 value with respect to time of approach for altitude, airspeed, and heading were calculated. To gauge quality of approach, time spent in the good range (1700 ± 50 ft; 170 ± 5 KCAS; 322 ± 1 degrees), in the fair range (1700 ± 75 ft; 170 ± 10 KCAS; 322 ± 2 degrees), target SSSE and r^2 target were calculated. To determine subjects' ability to maintain controlled flight during GS, mean SSSE and r^2 value with respect to time of approach for airspeed, heading (horizontal deviation), and glide slope angle (vertical deviation) were calculated. To gauge quality of performance, time

spent in the good range (170 + 5 KCAS; 322 ± 1 degrees; 0 ± 0.25 degrees), in the fair range (170 + 10 KCAS; 322 ± 2 degrees; 0 ± 0.50 degrees), target SSSE and r^2 target were calculated. To determine the weight of the SSSE values, an average of values for APP (and for GS) for both days runs for a given subject was calculated and points awarded for how close performance of an individual task was to that overall mean. Repeated measures ANOVA tests were used to determine if there were differences in performance grades based on run order, i.e., first vs. second ILS and for whether the control stick was loaded, using subject as a random factor and run number as a fixed factor.

TABLE III HERE

RESULTS

Sam Avoidance Simulation

Four small stature females and the medium stature female participated in these exposures. One of the small subjects terminated her second insertion early, which was attributed to insufficient rest between insertions. Another small subject completed her first series of turns but on her second attempt, completed only 17 sets (total of 51 turns) after displaying apparent Almost Loss of Consciousness (A-LOC) symptoms. She stopped flying, expressed feelings of confusion, shaking, and her hand made jerky involuntary motions until she noticed the symptoms and then it stopped. Some subjects reported arm discomfort as the task progressed.

The results from repeated measures ANOVA tests, used to determine if there were differences in performance grades based on run order (i.e. as the time performing the task increased) for each G-load, indicated no statistically significant differences based on run order were found. Based on t-test analysis, there were no statistically significant differences, within a given G-load, between the performance of the small and medium stature females. Summary performance grade results are shown in Table IV.

TABLE IV HERE

For the EMG analyses during this simulation, the last set of completed turns of the two subjects who ended their second insertions prematurely were included with the last set of turns of the other subjects. During the +7.2 Gz turns, subjects exerted statistically significant lower force during later turns compared with the earlier turns for the BRM (F=2.79, p=0.040) and the TM (F=2.67, p=0.042). Few statistically significant differences in effort were found during +5.4 or +3.6 Gz turns. There were also few statistically significant differences in Δf_{med} found based on the turn set number for +3.6 or +7.2 Gz turns. Overall for this group of subjects, Δf_{med} for BRM and BM decreased relative to unstressed levels while changes in f_{med} were variable for TM and DM. Table V shows the mean subject pool change in median EMG frequency (Hz) and heart rate (beats per minute) relative to the rest period immediately prior to the beginning of the SAM sequence. Table VI shows the mean subject pool change in EMG RMS (mV) relative to the effort exerted during the first SAM turn sequence.

TABLES V AND VI HERE

Bombing Simulation

Three of the small stature subjects participated in the bombing simulation. The subject pool recorded an overall 70.3% kill rate of ground targets. Note that it was apparent that these subjects had not received sufficient training time in the simulator in that two demonstrated greater success during their second bombing simulation compared with the first.

While significant differences in RMS and f_{med} between the three subjects were found, no statistically significant difference in RMS or f_{med} based on run order was demonstrated. Therefore, individual subject effort appeared to be consistent throughout each insertion. Changes in EMG frequency content and RMS power are shown in Tables VII and VIII.

TABLES VII AND VIII HERE

Level of G's pulled was also consistent. The variation in G-load ranged between ± 0.18 and ± 0.45 Gz. No statistically significant difference in G-load was demonstrated relative to run order ($F = 2.19$, $p = 0.086$), although subjects as a group tended to pull higher loads at later runs compared with early runs (on the order of +0.5 Gz). This might indicate increasing fatigue as subjects might have been losing the ability to produce a more graded effort on the control stick. No difference in weapons release altitude was demonstrated. However, the minimum altitude reached during pull out was significantly lower at the end of the insertion compared with earlier runs ($F = 5.11$, $p = 0.002$). Fisher's LSD test indicated that the minimum altitude during the last

run (at group mean altitude of 5,966 ft) was lower than runs 1, 4, 8 and 16. While this may be a function of increasing fatigue, subjects were still able to maintain their aircraft within the prescribed envelope. Note that only one subject reported subjective fatigue levels greater than moderate. Summary performance data is shown in Table IX.

TABLE IX HERE

Single Engine Failure Simulation

Three small stature subjects and the medium stature subject participated in the engine failure simulation. Flight performance was based on how well the subjects performed the ILS landing task. Results from the repeated measures ANOVA tests indicated that no statistically significant difference based on run order or stick load was found. Based on t-test analysis, there were no statistically significant differences between the performance of the small and medium stature subjects. Mean performance scores and fatigue ratings are shown in Table X.

TABLE X HERE

Two phases of the ILS task were selected to compute changes in EMG. These were (1) during straight and level flight during APP and (2) during the wave off procedure after following the glide slope toward the airport (WO). Due to technical problems, EMG recordings from all muscle groups could not be obtained. An analysis of the effort required during the unloaded versus loaded control stick condition indicated that during APP the EMG RMS values for BRM and BM were significantly greater during the loaded stick condition ($F = 17.51$, $p = 0.002$ and F

= 11.82, p = 0.009, respectively). BRM and TM f_{med} during the loaded stick condition were significantly lower during the loaded stick condition as well ($F = 44.76$, $p < 0.001$ and $F = 37.18$, $p = 0.0003$, respectively). At wave off, EMG RMS values for BRM and BM were also significantly greater during the loaded stick condition ($F = 17.72$, $p = 0.001$ and $F = 8.54$, $p = 0.019$, respectively) and the BRM and TM f_{med} during the loaded stick condition were also significantly lower than during the unloaded stick condition ($F = 22.83$, $p = 0.001$ and $F = 41.76$, $p = 0.0002$, respectively). Therefore, piloting with the control stick in the loaded condition required a greater flexor muscle group effort than in the control mode. Note that ANOVA results indicated that whether the control stick was loaded or not had no influence on the increase in heart rate measured during APP and WO.

Next, EMG measurements taken during the first ILS task were compared with the second task with the control stick loaded. Even though BRM, BM, and TM EMG RMS values were greater during performance of the second ILS task compared with the first, no statistically significant differences were demonstrated. During APP, there was a statistically significant decrease in BRM and TM f_{med} during the second ILS task compared with the first ($F = 38.90$, $p = 0.001$and $F = 51.58$, $p = 0.002$, respectively). A similar pattern occurred during the WO phase in which the decrease in BRM and TM f_{med} was significant ($F = 9.62$, $p = 0.021$ and $F = 41.43$, $p = 0.003$, respectively). While each subject indicated that her subjective fatigue increased during the simulation, subjects described the increase in fatigue as slight to moderate and the decrease in f_{med} indicated that at least some of the fatigue was muscular in origin. When comparing heart rate changes between the first and second APP or WO, ANOVA results indicate that the increase was statistically significant and may provide additional evidence of rising fatigue levels ($F = 12.52$, p

= 0.012 and F = 8.01, p = 0.03, respectively). Summary EMG Data is given in Tables XI and XII.

TABLES XI AND XII HERE

CONCLUSIONS

The most physically taxing simulation was the SAM avoidance task. This was the only task in which A-LOC symptoms were reported and subjects complained of arm pain. Despite the arduous nature of the task, statistical analysis of flight performance indicated no significant decline in subjects' ability to fly. There were no differences in performance between the small females and the medium stature female. For the highest G-load (+7.2 Gz), subjects exerted a statistically significantly lower amount of force during later turns compared with the earlier turns for the BRM and the TM muscle groups. Based on EMG analysis, no linear increase in muscle fatigue and no consistent increase in required muscle effort necessary to maintain control was demonstrated as more and more turns were performed.

Performance and effort was consistent during the bombing simulation with subjects achieving an overall 70% kill rate of ground targets. Subjective fatigue ratings were "very low" for two of the three subjects. No statistically significant increase in muscular fatigue was found during each simulation run. However, subjects may have had greater difficulty in fine muscular control during the later bombing runs in that they tended to pull higher +Gz loads than required and the minimum altitude reached after delivering ordnance was lower (though not below the minimum ceiling height).

Based on their ability to execute an ILS landing, performance scores were not significantly different between the first maneuver and after 20 minutes of flying with the control stick loaded to simulate the effort required to fly during a simulated single engine failure. Comparing the unloaded vs. loaded control stick conditions, significantly greater muscular effort was required by the BRM and BM groups to fly the loaded stick. While the level of muscular effort did not significantly change over time, decreases in EMG frequency content indicated that there was an increase in BRM and TM muscular fatigue. Increases in heart rate over time also implied an increase in fatigue even though subjective assessments of fatigue were rated "moderate" at most.

Within the scope of these tests, small stature females demonstrated the strength and endurance to control a simulated high performance aircraft while performing high-G turns, rollouts, maintaining a desired altitude and heading, a high pop maneuver, ILS landing maneuvers, flying to waypoints, and performing bombing runs, as indicated by statistical analysis of flight performance. However, cockpit accommodation and pilot reach limits may hinder the small stature pilot during flight emergencies requiring full stick authority or ejection during flat spin and arrestment.

Even though there were indications of changes in muscle effort and fatigue as the performance time of the various flight tasks increased, no significant decrements in performance were demonstrated. However, interpretation of the results presented in this report must be tempered with the knowledge that all subjects did not participate in all phases of the experiments. Even though a repeated measures design was used, statistical results should be interpreted as only an indication of how small stature females could perform in these situations. A larger sample of

subjects would increase the statistical power of these results. Deficiencies in muscular strength and endurance identified in this investigation may be overcome by suitable training in a motivated population. However, the grit and integrity that these subjects displayed is not sufficient to overcome the reach limitations which could limit their effectiveness in emergency situations or lead to a potentially dangerous mode of flying with the inertia reel unlocked. Accommodations in the areas of reach and clothing fit are essential to support the inclusion of this portion of the population in the high performance aircraft arena.

REFERENCES

1. Angel SM, Marley RJ Stadtlander L. Perceived exertion scales: toward development of improved verbal anchors. Proc. Human Factors & Ergonomics Soc. 38th Annual Meeting. 1994; p 626-30.

2. Basmajian JV, De Luca, CJ. Muscle alive. Their functions revealed by electromyography. 5th ed. Baltimore:Williams & Wilkins, 1985.

3. Borg GAV. Psychophysical bases of perceived exertion. Medicine and Sci. in Sports and Exercise. 1982; 14: 377-81.

4. Caldwell LS. The load-endurance relationship for a static manual response. Human Factors. 1964; 6:71-9.

5. Chaffin DB, Andersson GBJ. Occupational biomechanics, 2nd ed New York:John Wiley & Sons, Inc. 1991; Ch 4.

6. Khalil TM. An electromyographic methodology for the evaluation of industrial design. Human Factors. 1973; 15:257-64.

7. Laubach LL. Comparative muscular strength of men and women: A review of the literature. Aviat. Space Environ. Med. 1976; 47:534-42.

8. Laubach LL. Muscular strength of men and women: A comparative study. Wright Patterson AFB Technical Report AMRL-TR-75-32, May 1976.

9. Shender BS. "Female upper body dynamic strength requirements in high performance aircraft: A selected bibliography." Warminster:Naval Air Warfare Center Aircraft Division, Technical Report No. NAWCADWAR-95041-4.6, 1 June 1995.

CAPTIONS:

Table I. Acceleration grading scheme during SAM Avoidance task. Points awarded for maintaining the aircraft within target +Gz levels and ability to fly in a controlled manner. Mean: average over the entire series of turns at given G-load for a given subject. (See text for details.)

Table II. Altitude grading scheme during SAM Avoidance task. Points awarded for maintaining the aircraft within target altitude levels and ability to fly in a controlled manner. Mean: average over the entire series of turns at given altitude for a given subject; Entrance Altitude: points awarded for starting turn within 100 feet of target altitude (See text for details.)

Table III. Weighted grading scheme during Single Engine Failure task. Points apply for ILS Approach for altitude, airspeed, heading; and for the time spent following glide slope for airspeed, glide slope (vertical deviation), and heading (horizontal deviation). Points awarded for maintaining the aircraft within target levels and ability to fly in a controlled manner. Mean: average over both sets of ILS tasks for a given subject for both DFS insertions. (See text for details.)

Table IV. Mean performance scores for small stature subjects during SAM Avoidance task during each sequence consisting of three 4 s +Gz turns.

Table V. Mean change in median EMG frequency (Hz) and heart rate (HR, beats per minute) during the SAM Avoidance task for small stature subjects. Change is relative to rest period prior

to the first turn sequence. BRM: brachioradialis, BM: biceps, TM: triceps, DM: deltoid muscle groups.

Table VI. Mean change in EMG RMS value (mV) relative to the first turn sequence during the SAM Avoidance task for small stature subjects. BRM: brachioradialis, BM: biceps, TM: triceps, DM: deltoid muscle groups.

Table VII. Mean change in median EMG frequency (Hz) and heart rate (HR, beats per minute) during the Simulated Bombing task for small stature subjects, including change in frequency content during transition from flexion to extension in TM and DM during pullout after weapons release. Change is relative to rest period prior to the beginning of the task. BRM: brachioradialis, BM: biceps, TM: triceps, DM: deltoid muscle groups.

Table VIII. Mean change in EMG RMS value (mV) during the Simulated Bombing task for small stature subjects, including change in power during transition from flexion to extension in TM and DM during pullout after weapons release. Change is relative to effort during the first bombing run. BRM: brachioradialis, BM: biceps, TM: triceps, DM: deltoid muscle groups.

Table IX. Mean G load during pull out, altitude at weapons release, minimum altitude after release, subjective fatigue ratings during Simulated Bombing task for small stature subjects.

Table X. Mean performance scores and subjective fatigue ratings during the Single Engine Failure Simulation.

Table XI. Median EMG frequency (Hz) and change in heart rate (HR, beats per minute), relative to the beginning of the simulation, during the Single Engine Failure Simulation for small stature subjects, including both unloaded and loaded control stick conditions. BRM: brachioradialis, BM: biceps, TM: triceps, DM: deltoid muscle groups.

Table XII. EMG RMS values (mV) during the Single Engine Failure Simulation for small stature subjects, including both unloaded and loaded control stick conditions. BRM: brachioradialis, BM: biceps, TM: triceps, DM: deltoid muscle groups.

Table I.

Factor	Points	Distribution	Factor	Points	Distribution
Percentage of time spent in "Good Range (GR)"	7	$90 \leq GR \leq 100$	Percentage of time spent in "Fair Range (FR)"	3	$70 \leq FR \leq 100$
	6	$80 \leq GR < 90$		2	$40 \leq FR < 70$
	5	$70 \leq GR < 80$		1	$10 \leq FR < 40$
	4	$60 \leq GR < 70$		0	$10 < FR$
	3	$50 \leq GR < 60$			
	2	$30 \leq GR < 50$			
	1	$10 \leq GR < 30$			
	0	$10 < GR$			
Target SSSE and Mean SSSE (controllability)	10	≤ mean * 10%	r^2 Target and r^2 Time (controllability)	10	$0.9 \leq r^2 \leq 1.0$
	9	≤ mean * 20%		9	$0.8 \leq r^2 < 0.9$
	8	≤ mean * 30%		8	$0.7 \leq r^2 < 0.8$
	7	≤ mean * 40%		7	$0.6 \leq r^2 < 0.7$
	6	≤ mean * 50%		6	$0.5 \leq r^2 < 0.6$
	5	≤ mean * 60%		5	$0.4 \leq r^2 < 0.5$
	4	≤ mean * 70%		4	$0.3 \leq r^2 < 0.4$
	3	≤ mean * 80%		3	$0.2 \leq r^2 < 0.3$
	2	≤ mean * 90%		2	$0.1 \leq r^2 < 0.2$
	1	≤ mean * 100%		1	$0.05 \leq r^2 < 0.1$
	0	> mean * 100%		0	$r^2 < 0.05$

Table II.

Factor	Points	Distribution	Factor	Points	Distribution
Percentage of time spent in "Good Range (GR)"	5	$90 \leq GR \leq 100$	Percentage of time spent in "Fair Range (FR)"	3	$70 \leq FR \leq 100$
	4	$70 \leq GR < 90$		2	$40 \leq FR < 70$
	3	$50 \leq GR < 70$		1	$10 \leq FR < 40$
	2	$30 \leq GR < 50$		0	$10 < FR$
	1	$10 \leq GR < 30$			
	0	$10 < GR$			
Entrance Altitude	2	± 100 ft			
Target SSSE and Mean SSSE (controllability)	10	≤ mean * 10%	r^2 Target and r^2 Time (controllability)	10	$0.9 \leq r^2 \leq 1.0$
	9	≤ mean * 20%		9	$0.8 \leq r^2 < 0.9$
	8	≤ mean * 30%		8	$0.7 \leq r^2 < 0.8$
	7	≤ mean * 40%		7	$0.6 \leq r^2 < 0.7$
	6	≤ mean * 50%		6	$0.5 \leq r^2 < 0.6$
	5	≤ mean * 60%		5	$0.4 \leq r^2 < 0.5$
	4	≤ mean * 70%		4	$0.3 \leq r^2 < 0.4$
	3	≤ mean * 80%		3	$0.2 \leq r^2 < 0.3$
	2	≤ mean * 90%		2	$0.1 \leq r^2 < 0.2$
	1	≤ mean * 100%		1	$0.05 \leq r^2 < 0.1$
	0	> mean * 100%		0	$r^2 < 0.05$

Table III.

Factor	Points	Distribution	Factor	Points	Distribution
Percentage of time spent in "Good Range (GR)"	3.0	$90 \leq GR \leq 100$	Percentage of time spent in "Fair Range (FR)"	1.0	$70 \leq FR \leq 100$
	2.5	$75 \leq GR < 90$		0.5	$30 \leq FR < 70$
	2.0	$60 \leq GR < 75$		0.0	$30 < FR$
	1.5	$40 \leq GR < 60$			
	1.0	$20 \leq GR < 40$			
	0.5	$10 \leq GR < 20$			
	0.0	$10 < GR$			
Target SSSE and Mean SSSE (controllability)	4.0	$\leq$ mean * 10%	r^2 Target and r^2 Time (controllability)	2.0	$0.9 \leq r^2 \leq 1.0$
	3.5	$\leq$ mean * 20%		1.5	$0.65 \leq r^2 < 0.9$
	3.0	$\leq$ mean * 30%		1.0	$0.3 \leq r^2 < 0.65$
	2.5	$\leq$ mean * 40%		0.5	$0.1 \leq r^2 < 0.3$
	2.0	$\leq$ mean * 50%		0.0	$r^2 < 0.1$
	1.5	$\leq$ mean * 70%			
	1.0	$\leq$ mean * 90%			
	0.5	$\leq$ mean * 100%			
	0.0	$>$ mean * 100%			

Table IV.

Turn Sequence Number	+7.2 Gz Turn	+3.6 Gz Turn	+5.4 Gz Turn
1	55.3 ± 17.1	59.0 ± 11.3	66.3 ± 5.3
2	70.0 ± 13.7	62.4 ± 11.7	62.1 ± 8.6
3	71.1 ± 10.0	68.8 ± 13.4	54.3 ± 12.2
4	71.8 ± 4.6	57.6 ± 10.3	60.3 ± 10.5
5	71.3 ± 4.6	58.8 ± 14.2	61.3 ± 14.7
6	72.9 ± 4.5	61.9 ± 9.4	61.6 ± 15.2
7	68.3 ± 9.7	66.6 ± 8.1	68.8 ± 3.5
8	71.6 ± 5.5	64.4 ± 4.8	56.3 ± 12.6
9	72.6 ± 5.9	62.0 ± 4.8	67.5 ± 2.4
10	72.9 ± 9.4	61.9 ± 7.2	68.1 ± 6.9
11	75.8 ± 8.5	62.9 ± 13.0	60.5 ± 10.5
12	67.5 ± 5.7	63.8 ± 4.9	67.9 ± 6.4
13	66.6 ± 8.6	61.4 ± 3.1	66.1 ± 7.8
14	69.8 ± 7.2	63.5 ± 7.0	63.5 ± 7.0
15	76.9 ± 4.7	63.9 ± 4.0	56.6 ± 6.1
16	74.8 ± 6.6	66.9 ± 3.0	67.5 ± 7.0
17	72.9 ± 3.1	60.5 ± 11.2	63.0 ± 15.4
18	73.5 ± 13.3	70.5 ± 6.8	68.4 ± 15.5
19	78.0 ± 9.4	68.4 ± 7.8	56.9 ± 19.5
20	73.5 ± 6.5	56.8 ± 7.5	60.6 ± 8.4
21	71.5 ± 9.5	65.0 ± 12.8	66.0 ± 5.6
22	76.3 ± 6.0	67.3 ± 7.8	60.4 ± 7.7
23	75.4 ± 7.2	64.1 ± 9.5	70.4 ± 5.7
24	76.9 ± 13.2	66.3 ± 4.6	73.6 ± 10.9

Table V.

Turn Sequence Number	BRM (Hz)	BM (Hz)	TM (Hz)	DM (Hz)	HR (bpm)
+7.2 Gz					
1	-11.1 ± 7.2	-4.3 ± 8.5	-9.0 ± 5.5	-8.3 ± 5.7	17.3 ± 5.4
4	-11.2 ± 6.8	-3.9 ± 6.1	-7.6 ± 3.9	-7.6 ± 5.4	21.6 ± 11.5
8	-11.4 ± 6.4	-4.1 ± 6.8	-6.4 ± 7.6	-5.5 ± 9.6	22.0 ± 13.1
12	-11.6 ± 7.0	-2.1 ± 7.5	-6.9 ± 6.9	-5.6 ± 9.8	22.0 ± 12.4
16	-9.1 ± 6.8	-1.3 ± 10.6	-7.1 ± 7.8	-3.7 ± 9.4	24.0 ± 17.2
20	-10.8 ± 9.6	-3.8 ± 8.5	-8.0 ± 7.3	-8.5 ± 5.4	23.9 ± 15.8
24	-10.6 ± 8.7	-1.6 ± 9.2	-8.5 ± 8.4	-5.2 ± 9.6	22.9 ± 17.2
+3.6 Gz					
1	-22.0 ± 11.8	-8.2 ± 9.0	-15.7 ± 2.6	-0.7 ± 9.5	-2.8 ± 6.4
4	-23.2 ± 8.1	-7.6 ± 9.2	-17.0 ± 3.2	-2.3 ± 8.3	2.6 ± 9.9
8	-25.7 ± 10.8	-7.7 ± 7.9	-15.0 ± 3.3	1.9 ± 10.2	2.1 ± 10.3
12	-23.8 ± 9.0	-7.1 ± 8.1	-14.4 ± 5.1	4.4 ± 11.4	1.4 ± 10.5
16	-19.7 ± 5.6	-4.5 ± 7.6	-14.4 ± 5.1	5.9 ± 8.1	3.9 ± 13.5
20	-16.3 ± 5.1	-4.2 ± 5.7	-13.6 ± 5.2	3.9 ± 9.7	5.2 ± 15.6
24	-23.3 ± 10.7	-6.9 ± 7.1	-15.5 ± 4.1	3.8 ± 10.0	3.6 ± 14.4
+5.4 Gz					
1	-15.8 ± 10.6	-6.7 ± 7.8	-15.4 ± 10.8	-2.4 ± 9.8	4.3 ± 7.6
4	-14.0 ± 13.0	-7.2 ± 8.1	-12.8 ± 13.4	-0.5 ± 10.9	7.2 ± 8.4
8	-18.0 ± 10.7	-7.5 ± 6.2	-15.3 ± 11.6	-1.7 ± 9.0	7.0 ± 8.9
12	-16.4 ± 12.3	-6.1 ± 8.1	-14.7 ± 12.2	-0.2 ± 9.3	8.4 ± 9.3
16	-15.0 ± 11.1	-4.4 ± 10.5	-18.0 ± 11.1	1.5 ± 10.6	11.6 ± 11.4
20	-17.4 ± 10.2	-8.2 ± 9.1	-18.9 ± 9.2	0.2 ± 11.2	10.7 ± 12.0
24	-18.1 ± 11.4	-5.8 ± 8.5	-16.3 ± 9.2	1.0 ± 10.6	9.0 ± 13.9

Table VI.

Turn Sequence Number	BRM (mV)	BM (mV)	TM (mV)	DM (mV)
+7.2 Gz				
4	-148 ± 74	-55 ± 51	-16 ± 19	-21 ± 17
8	-236 ± 107	-119 ± 105	-47 ± 49	-29 ± 37
12	-238 ± 145	-131 ± 151	-46 ± 44	-40 ± 52
16	-263 ± 164	-164 ± 145	-44 ± 57	-50 ± 40
20	-264 ± 146	-112 ± 61	-32 ± 17	-50 ± 47
24	-273 ± 163	-112 ± 77	-47 ± 18	-45 ± 76
+3.6 Gz				
4	-36 ± 46	-23 ± 224	-4 ± 16	-2 ± 15
8	-86 ± 63	-35 ± 33	-15 ± 10	-12 ± 13
12	-76 ± 80	-43 ± 45	-14 ± 6	-13 ± 14
16	-68 ± 71	-51 ± 43	-11 ± 7	-14 ± 13
20	-78 ± 71	-60 ± 43	-17 ± 10	-12 ± 12
24	-79 ± 86	-53 ± 50	-19 ± 12	-16 ± 12
+5.4 Gz				
4	-38 ± 59	-8 ± 27	-1 ± 17	-1 ± 4
8	-73 ± 77	-27 ± 38	-12 ± 4	-25 ± 65
12	-90 ± 48	-45 ± 36	-21 ± 15	-28 ± 61
16	-118 ± 56	-59 ± 33	-21 ± 14	-29 ± 60
20	-68 ± 61	-53 ± 5	-13 ± 24	-31 ± 68
24	-95 ± 58	-42 ± 42	-18 ± 21	-41 ± 71

Table VII.

Bombing Run Number	BRM (Hz)	BM (Hz)	TM (Hz)	DM (Hz)	HR (bpm)
Run 1	-15.8 ± 10.4	-8.6 ± 11.6	-10.9 ± 5.6	-12.7 ± 4.3	24.4 ± 9.5
Run 4	-14.2 ± 1.7	-12.8 ± 6.6	-11.7 ± 5.7	-15.4 ± 5.3	25.7 ± 6.4
Run 8	-18.0 ± 4.6	-17.6 ± 2.7	-15.0 ± 1.9	-19.7 ± 0.9	23.9 ± 7.5
Run 12	-15.3 ± 2.8	-9.5 ± 10.8	-10.1 ± 5.3	-14.5 ± 3.7	19.3 ± 7.6
Run 16	-16.4 ± 5.7	-9.8 ± 12.2	-9.3 ± 2.3	-18.2 ± 3.7	26.4 ± 8.7
Last Run	-16.9 ± 5.8	-22.6 ± 12.6	-11.6 ± 7.1	-16.8 ± 5.4	19.5 ± 8.8
During Pullout:			TM (Hz)	DM (Hz)	
Run 1			13.0 ± 13.5	-4.5 ± 6.1	
Run 4			13.4 ± 7.7	-6.8 ± 5.9	
Run 8			5.6 ± 9.7	-9.3 ± 7.3	
Run 12			12.2 ± 10.9	-8.0 ± 4.1	
Run 16			9.7 ± 10.4	-5.5 ± 6.4	
Last Run			10.3 ± 15.1	-9.4 ± 7.5	

Table VIII.

Bombing Run Number	BRM (mV)	BM (mV)	TM (mV)	DM (mV)
Run 4	16 ± 139	61 ± 97	15 ± 37	8 ± 22
Run 8	22 ± 116	54 ± 87	9 ± 28	3 ± 21
Run 12	3 ± 109	71 ± 106	10 ± 40	15 ± 22
Run 16	19 ± 136	70 ± 115	8 ± 47	13 ± 30
Last Run	1 ± 136	58± 158	14 ± 63	16 ± 20
During Pullout			TM (mV)	DM (mV)
Run 4			-1 ± 65	-30 ± 78
Run 8			-10 ± 62	-33 ± 26
Run 12			-10 ± 72	-34 ± 58
Run 16			-29 ± 60	-46 ± 61
Last Run			10 ± 62	-32 ± 37

Table IX.

Bombing Run Number	Peak G During Pull Out	Altitude at Weapons Release (ft)	Minimum Altitude (ft)	Range in Reported Subjective Fatigue
Run 1	6.6 ± 0.6	7688 ± 34	7029 ± 61	none
Run 4	7.0 ± 0.5	7713 ± 111	6474 ± 181	none to very, very slight
Run 8	7.2 ± 0.2	7891 ± 163	6646 ± 258	none to moderate
Run 12	7.1 ± 0.5	7600 ± 161	6331 ± 132	none to somewhat strong
Run 16	7.2 ± 0.1	7738 ± 125	6438 ± 110	very, very slight to strong
Last Run	7.1 ± 0.4	7611 ± 390	5966 ± 438	very, very slight to strong

Table X.

Subject	Unloaded Control Stick	First ILS maneuver (loaded control stick)	Fatigue during first ILS	Second ILS Maneuver (loaded control stick)	Fatigue during second ILS
1	69.3 ± 1.1	65.3 ± 1.8	very, very slight	62.3 ± 6.0	somewhat strong
2	65.0 ± 1.4	62.3 ± 7.4	none	55.5 ± 14.1	very slight
3	63.8 ± 5.3	65.8 ± 0.4	none	75.5 ± 4.2	slight

Table XI.

ILS Phase	BRM (Hz)	BM (Hz)	TM (Hz)	DM (Hz)	ΔHR (bpm)
Unloaded					
Intercept	85.2 ± 12.7	67.1 ± 2.6	91.1 ± 8.2	76.9 ± 8.6	5.1 ± 6.6
Wave Off	81.3 ± 20.0	71.2 ± 15.3	93.5 ± 8.7	75.5 ± 10.1	15.3 ± 6.4
Loaded					
Intercept 1	65.6 ± 0.8	67.1 ± 2.4	76.4 ± 6.3	78.5 ± 6.0	0.4 ± 2.8
Wave Off 1	60.9 ± 1.9	66.9 ± 2.8	73.5 ± 5.1	79.3 ± 6.6	9.0 ± 7.9
Intercept 2	57.2 ± 3.4	65.3 ± 3.0	67.6 ± 4.5	74.2 ± 2.0	15.7 ± 7.6
Wave Off 2	54.8 ± 4.5	64.2 ± 1.3	66.3 ± 2.9	73.9 ± 4.2	19.5 ± 8.1

Table XII.

ILS Phase	BRM (mV)	BM (mV)	TM (mV)	DM (mV)
Unloaded				
Intercept	125 ± 141	63 ± 22	39 ± 16	65 ± 46
Wave Off	110 ± 95	71 ± 21	39 ± 17	62 ± 60
Loaded				
Intercept 1	307 ± 194	191 ± 103	40 ± 5	38 ± 22
Wave Off 1	299 ± 166	210 ± 134	39 ± 4	32 ± 20
Intercept 2	447 ± 282	272 ± 118	52 ± 10	40 ± 27
Wave Off 2	454 ± 274	280 ± 184	48 ± 10	41 ± 32

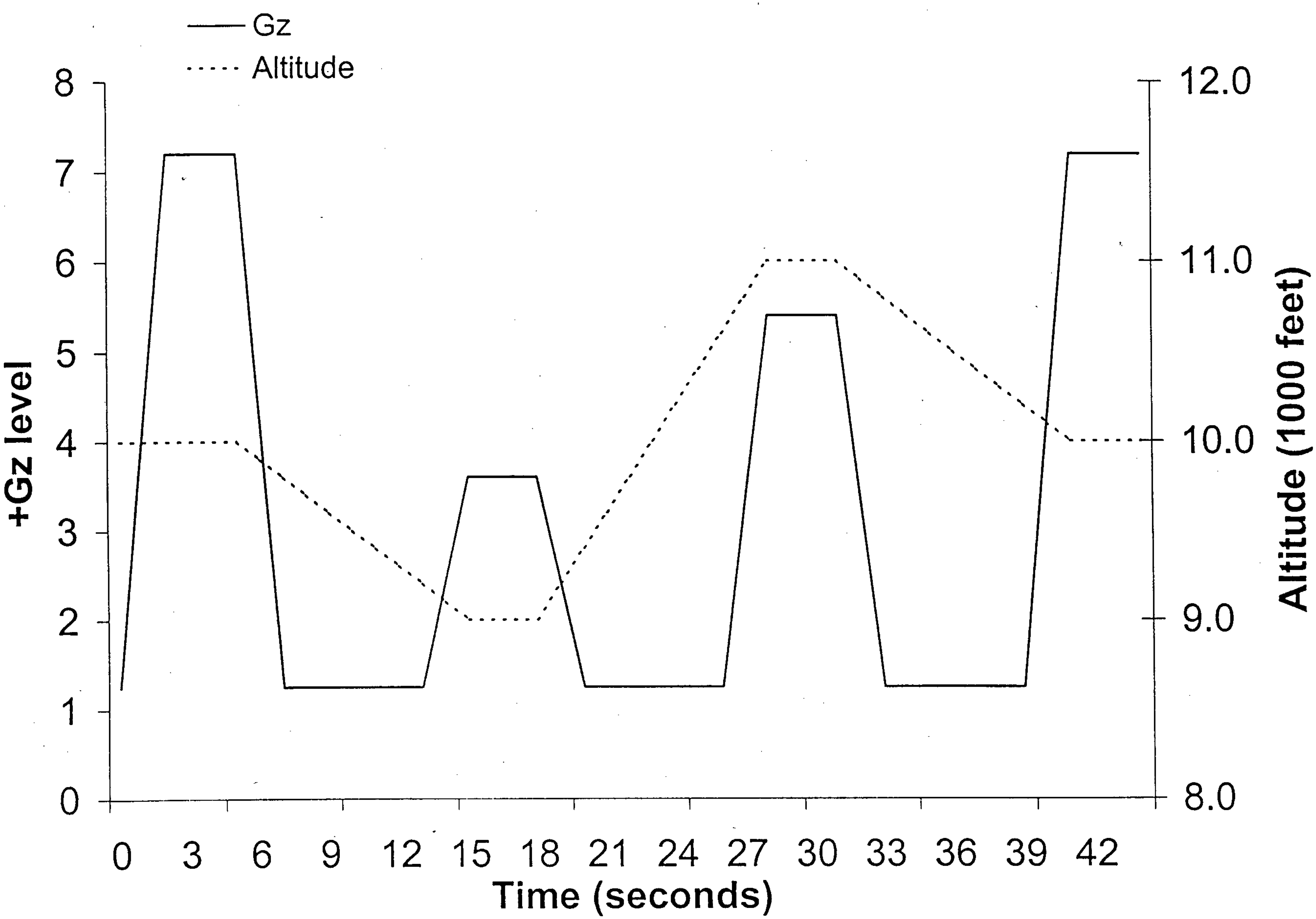
FIGURE CAPTIONS:

Fig.1. Idealized +Gz load and altitude change pattern during one set of turns of the SAM Avoidance task.

Fig. 2. Idealized +Gz load and altitude change pattern during one run of the Bombing task. The sequence displayed includes the +4 Gz turn about after flying away from the target airport, the approach, inverting and rolling upright to release the ordnance, and the high +Gz pull out after ordnance delivery.

ACKNOWLEDGMENTS

We would like to thank CAPT Michael Lilienthal and CAPT Dennis McBride for their sponsorship, encouragement and support. We are also grateful for Mr. L. Doug Waldman's help in designing the flight simulations used in this project, LT Dylan Schmorrow and the Biomedical Support Branch (Code 4.6.4.2) for their help in preparing the subjects for centrifuge runs and providing safety monitoring, CDR David McGowan for providing the medical monitoring during this project, and the volunteer test subjects for their invaluable assistance without which this project would have been impossible.



Gz
Altitude
+Gz level
Altitude (1000 feet)
Time (seconds)
0
1
2
3
4
5
6
7
8
8.0
9.0
10.0
11.0
12.0
0
3
6
9
12
15
18
21
24
27
30
33
36
39
42

Fig. 1.

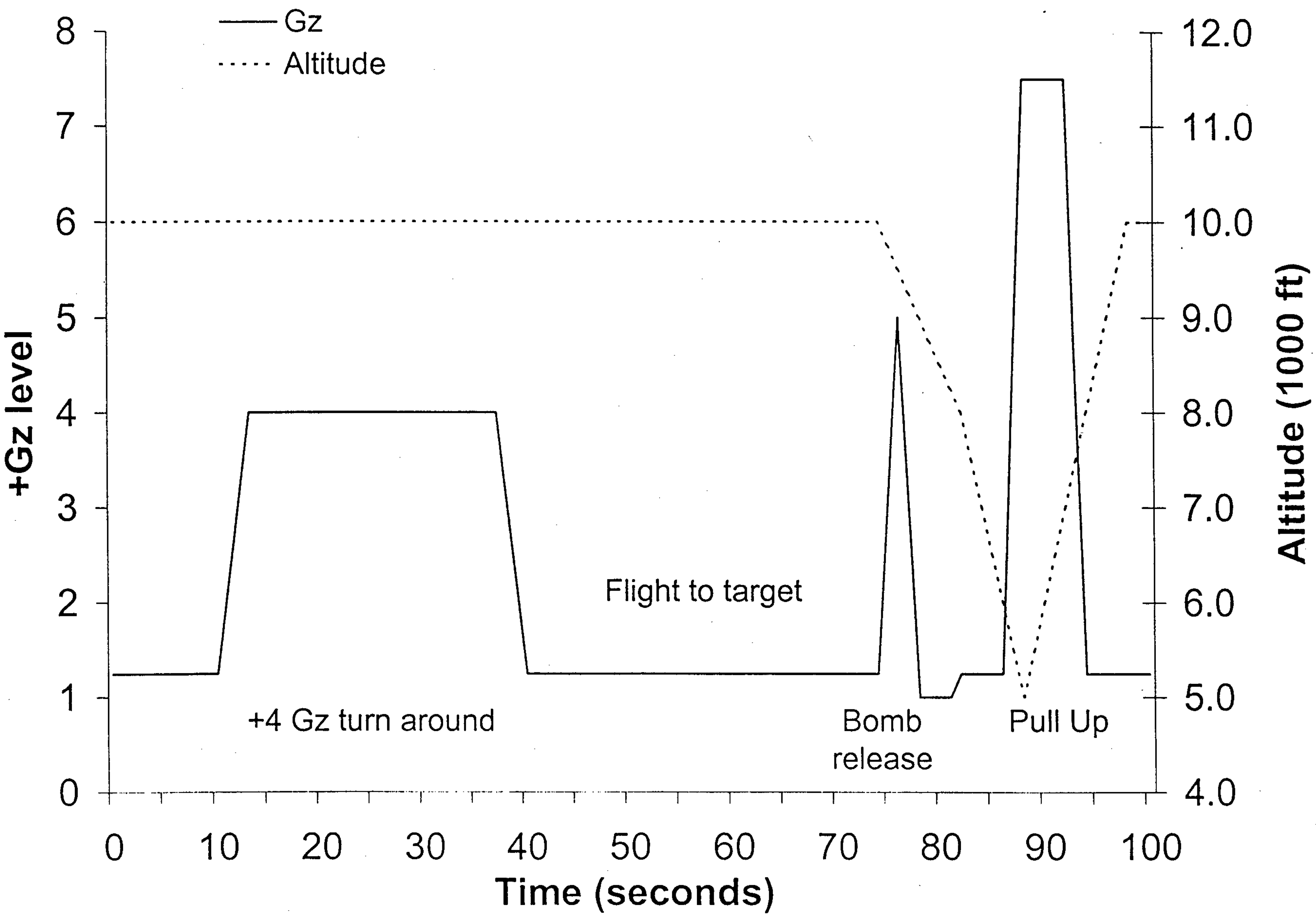

Gz
Altitude
8
7
6
5
4
3
2
1
0
+Gz level
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
Altitude (1000 ft)
0
10
20
30
40
50
60
70
80
90
100
Time (seconds)
+4 Gz turn around
Flight to target
Bomb release
Pull Up

Fig. 2.